Buried Ordnance Locator

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LONG-TERM GOALS

Explosive ordnance disposal (EOD) technicians require the capability for standoff detection and classification of buried anomalies. Current fielded man-portable sensors provide little to no standoff detection and no classification of detected anomalies. The development and demonstration of techniques for standoff detection and classification of buried metallic and non-metallic unexploded ordnance (UXO) will result in a prototype man-portable multi-element electromagnetic sensor array system.

OBJECTIVES

The objectives of this program are to: (1) Collect experimental time domain electromagnetic (TDEM) data to determine baseline EM signatures of targets with simple geometrical shapes, (2) Use the experimental data to validate results and theoretical knowledge to develop computer algorithms for forward and inverse modeling of the responses of TDEM systems to UXO targets (these algorithms will be the basis for characterization of buried anomalies), and (3) Assess the capability of a multi-element magnetic field sensor array to detect buried UXO-like items and classify detected items as UXO or non-UXO shaped. More specifically, demonstrate that a giant magnetoresistive (GMR) or high temperature superconducting quantum interference device (HT SQUID) multi-element gradient sensor can determine the location of a UXO item at an appropriate range relative to target size and magnetic signature (e.g., a 150 mm projectile at a range of 4 meters) with an EM source and provide information for shape assessment.

APPROACH

This program was started with two prime contractors. Geometrics pursued SQUID technology in an effort to develop a sensitive passive gradiometer. Blackhawk started developing the necessary components for a TDEM active locator for detection and characterization of UXO. Since that time, Geometrics bought Blackhawk, resulting in a new company named Blackhawk Geometrics. The

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approach has primary components, which are the development of an EM sensor, a tensor array, algorithms to enable classification, and a test bed for field characterization.

Sensors. Efforts sponsored by ONR will be leveraged to develop Magnetoresistive Spin Dependent Tunneling (SDT) Sensors suitable for the EOD application. New fabrication processes will be investigated to improve the bandwidth and sensitivity beyond state-of-the-art SDT devices. In order to obtain improvements in sensitivity, thicker coils for feedback and biasing currents are needed. Low temperature deposition and insulation processes will be developed to ensure the underlying SDT material is not damaged. Sensor assemblies will be developed for use in wide bandwidth operations. A set of low frequency assemblies will also be fabricated with an expected noise floor of 1 nT/rt Hz at 1 Hz.

Tensor Array. The current design philosophy for the SDT sensor is to create a cube using 54 SDT sensors. Each face of the cube will have nine SDT sensors in a 3 x 3 matrix. Each pair of SDT sensors on opposite sides of the cube will act as a gradiometer. The term for this arrangement is a MagnetoCube array. A MagnetoCube tensor array will be designed and fabricated.

An 8-element HT SQUID tensor array will be designed and fabricated. This includes development of all the associated electronics and the liquid nitrogen dewar system. The basic design will be patterned after the Tristan model G377 3-axis geophysical magnetometer. After fabrication, the tensor array performance will be characterized in a low field test chamber. Modifications will be made if required. Field tests will be conducted to determine noise, frequency response and dynamic range and to determine other parameters, such as noise vibration and field worthiness.

The Magnetocube tensor array will be integrated with the HT SQUID tensor array. Each array will be characterized separately in laboratory tests before the combined sensor is fabricated. The combined system will undergo testing to characterize the noise as a function of temperature and mechanical stability. System interactions will be studied to determine if any interference exists between the two types of sensors. Operating modes, dynamic range, frequency range and sensitivity, cross talk, sensor noise, power, calibration, and multichannel issues will all be addressed as necessary. Tests of the combined sensor assembly will be performed in a low magnetic field test chamber. Finally, a field test will be conducted to verify proper operation and capability of the system.

The sensor selected for the final buried ordnance locator design could be any of the three sensors listed above: MagnetoCube tensor array, SQUID tensor array, or a combination of the two. None of the sensors has been pre-selected for the final design. The decision on which sensor to use will be based on sensitivity, bandwidth, noise levels, frequency response, dynamic range, and other issues pertaining to system design and compatibility with field environments.

Algorithm Development and UXO TDEM Response Characterization. Data will be collected to create a library of experimental TDEM measurements. A test bed containing suspended and buried inert UXO and canonical objects simulating typical UXO will be used. The sensors used to collect the data will be the EM61-3D and a 3-axis HT SQUID array. During development of the hardware, Blackhawk Geometrics will also develop software to operate the sensor array. Algorithm development includes forward and inverse modeling, sensor optimization, model-based discrimination, and databased discrimination. Software for the reduction of noise will also be developed.

Test Bed. A portable EM source will be designed, developed and tested for use with the combined sensor array. A belt portable data acquisition and control system will be developed to interface with the combined sensor array. The array, control console, and software will be integrated into a single system. The system will then be tested and modifications will be made if necessary. The final sensor design will be selected for the test bed. All system components will be integrated into a buried ordnance locator prototype. The prototype will be field-tested and all data collected will be analyzed.

WORK COMPLETED

A system design study has been completed and field tests performed using a 3-axis HT SQUID array assembled by Conductus. The target for the field test was an inert 105-mm projectile made of soft steel. The target was moved, while the SQUID array remained in place.

The experimental data has been used to conduct mathematical investigations, develop and code algorithms and validate codes. The modeling was validated through the use of data collected with the Geonics EM-61 and EM61-3C using spherical and rectangular aluminum targets.

Additional laboratory and field testing has been conducted with the EM61-3D to determine background noise levels and EM response from baseline targets. Magnetic measurements have been collected over a 10 meter x 10 meter survey grid on simple target shapes, including steel and aluminum spheres, aluminum cubes, and steel cylinders. Additional measurements will be made in the near future.

RESULTS

Substantial progress was made in the theoretical and numerical implementation of the mean field theory for ellipsoidal and spheroidal scatterers. These shapes can be used to accurately model typical UXO objects and metallic components of land mines.

The final buried ordnance locator prototype will contain an EM source to radiate and induce electrical currents in potential targets. These targets will then emit a secondary EM field as the induced currents deteriorate. This secondary field is called the external field, and will be measured by the sensors in the buried ordnance locator. To theoretically calculate the external field radiated by a particular target, the internal field of that target must be determined. In mean field theory, this is accomplished by computing the Taylor series expansion coefficients to the second or third order. During this reporting period, the Taylor series coefficients were determined to the second order and specialized to the ellipsoidal and spheriodal cases. Next, a method was worked out to compute the external field, given the internal field (determined from the series expansion). Since the external field is what is measured by magnetic sensors, these results will be verified with data collected by the EM61-3D.

IMPACT/APPLICATIONS

An EM-based man-portable tool with the capability to detect and classify ordnance targets will enable EOD technicians to better define hazards in the field. Once the hazards are known, the proper tools and procedures can be identified and used to dispose of the hazard safely.

TRANSITIONS

Current advanced development system requirements already exist that are awaiting appropriate technological developments before proceeding. The result of the Analysis of Alternatives (AOA) for an Advanced Ordnance Locator (AOL) performed in FY96 was to wait for characterization technology to mature before proceeding with an acquisition program. There is an AOA scheduled for FY01 to develop an AOL. Developments in sensor technology from this 6.2 effort will feed directly into the development of the AOL. PMSEOD has allotted funding in the Program Objective Memorandum (POM) for FY01 and beyond.

RELATED PROJECTS

DOE is conducting an effort to develop a superconducting magnetometer/gradiometer for advanced geophysical imaging. This effort is using SQUIDs to obtain EM measurements in boreholes. Some of the DOE work is directly applicable to our Standoff Detection effort. In fact, SQUID equipment used for the initial field tests was based on the DOE effort.

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